

AFOSR-TR-97

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## REPORT DOCUMENTATION PAGE

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<b>REPORT DOCUMENTATION PAGE</b>			
<p><b>1. AGENCY USE ONLY (Leave blank)</b></p> <p><b>2. REPORT DATE</b> February 21, 1997</p> <p><b>3. REPORT TYPE AND DATES COVERED</b> Final Technical 9/95 - 8/96</p>			
<p><b>4. TITLE AND SUBTITLE</b> Instrumentation for frequency-modulation spectroscopy and phase-sensitive detection of photon echoes for hole-burning optical storage</p>			<p><b>5. FUNDING NUMBERS</b> FY3620-93-1-0046 <i>(01103D 3484) US</i></p>
<p><b>6. AUTHOR(S)</b> A. Gorokhovsky I. Zeylikovich R. R. Alfano</p>			<p><b>7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)</b> Department of Physics The City College of New York 138 Street &amp; Convent Avenue New York, NY 10031</p>
<p><b>8. PERFORMING ORGANIZATION REPORT NUMBER</b> Final Technical Report</p>			<p><b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> AFOSR/NE Building 410, Bolling Air Force Base Washington D.C. 20332-6448</p>
<p><b>10. SPONSORING / MONITORING AGENCY REPORT NUMBER</b> <i>F49620-95-1-0494</i></p>			
<p><b>11. SUPPLEMENTARY NOTES</b> The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.</p>			
<p><b>12a. DISTRIBUTION / AVAILABILITY STATEMENT</b> Approved for public release; distribution unlimited.</p>		<p><b>12 b. DISTRIBUTION CODE</b></p>	
<p><b>13. ABSTRACT (Maximum 200 words)</b> Instrumentation for frequency-modulation spectroscopy studies of hole-burning materials for optical storage, and a phase-sensitive interferometric correlator for photon echoes detection has been purchased. Applications of phase-sensitive correlator to phase stability characterization and heterodyne detection of optical signals were demonstrated using the equipment.</p>			
<p><b>14. SUBJECT TERMS</b></p>		<p><b>15. NUMBER OF PAGES</b> 8</p>	
		<p><b>16. PRICE CODE</b></p>	
<p><b>17. SECURITY CLASSIFICATION OR REPORT</b> UNCLASSIFIED</p>	<p><b>18. SECURITY CLASSIFICATION OF THIS PAGE</b> UNCLASSIFIED</p>	<p><b>19. SECURITY CLASSIFICATION OF ABSTRACT</b> UNCLASSIFIED</p>	<p><b>20. LIMITATION OF ABSTRACT</b> UL</p>

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**INSTRUMENTATION FOR FREQUENCY-MODULATION SPECTROSCOPY  
AND PHASE-SENSITIVE DETECTION OF PHOTON ECHOES FOR HOLE-  
BURNING OPTICAL STORAGE**

**Air Force Office of Scientific Research**

**Contract/ Grant Number: FY 3620-93-1-0046**

**FINAL REPORT**

**A. Gorokhovsky, I. Zeylikovich and R. R. Alfano**

Instruments were acquired for (A) frequency-modulation spectroscopy for studies of hole-burning materials for optical storage, and (B) an phase-sensitive interferometric correlator for photon echoes detection using the funds under the AFOSR Research Instrumentation Program.

**Part A. The instrument for frequency-modulation spectroscopy**

The following instruments were purchased for frequency-modulation spectroscopy for studies of hole-burning materials for optical storage:

1. Optical chopper New Focus 3501
2. Photomultiplier tube Hamamatsu R 943-02
3. Cooled Photomultiplier Housing ETI LCT-
4. Shatter Product for Research PR 305
5. Monochromator McPherson 2035
6. Translation Stage Newport and Micrometer Newport 436A
7. Filter Wheel New Focus 5434 with Filters
8. Polarization Compensator New Focus 5540
9. RF Synthesized Sweeper HP 83752A
10. RF Spectrum Analyzer HP 8560E
11. RF Power Amplifier ENI 607L
12. Phase Modulator Quantum Technology TWAP-11
13. Si detector EOS S-025/H with power supply (two)

14. Avalanche PD Module Hamamatsu C5658
15. Laser Spectrum Analyzer Burleigh SA-200-B2
16. Acousto-Optic Frequency Shifter Brimrose TEF 270-100 with Driver VFF-270 (two)
17. Single Frequency Diode laser ECV-2010 (shipment has been delayed until 02/28/97 due to manufacturing problems)
18. Boxcar Modules Stanford Research 280, 250 (two), 245, and 235
19. Delay Generator Stanford Research DG 535
20. Polarizer Optics for Research PE-10-VIR (two)
21. Si detector Thorlabs 50 MHz (two)

These items acquired under the Research Instrumental Program will be used to build a novel type frequency-modulation spectroscopy instruments to measure extremely weak narrow absorption features in spectra of the materials under investigation. The apparatus will be built at The College of Staten Island of CUNY, where Dr. Gorokhovsky will continue research for AFOSR on materials for spectral hole-burning optical storage in cooperation with The City College.

#### **Part B. Time-resolved interferometric correlation instrument**

The following items were purchased:

1. CCD camera ATC-200
2. 460MST-2X Imaging Spectrograph.
3. SLM-256 spatial light modulator masks.
4. ATC04010-04015 linear positioning stage (three) incl. HDZ4 bracket and VIIR-4-A UNIDEX stepping motor controller
5. Gateway 2000 Computer
6. Compensated attenuator
7. 845HP digital shutter system
8. Optical and mechanical components for interferometric correlator.

These items acquired under the Research Instrumentation Program are used to build novel interferometric correlators for the following three projects:

## **1. Time-resolved spectral interferometry to characterize the phase stability of pulse stream.**

Interferometric correlator combined with the spectrometer was built to measure long time phase stability of ultrashort pulse stream. 460MST-2X Imaging Spectrograph, ATC04010-04015 linear positioning stage, compensated attenuator, 845HP digital shutter system, optical and mechanical components are acquired. The experimental setup is shown in Fig.1. The phase stability of the femtosecond pulses produced by a colliding pulse mode-locked ( CPM ) dye ring laser with the four-prisms was measured. Measurements showed that CPM laser pulses have short time (10-20 s) phase stability.

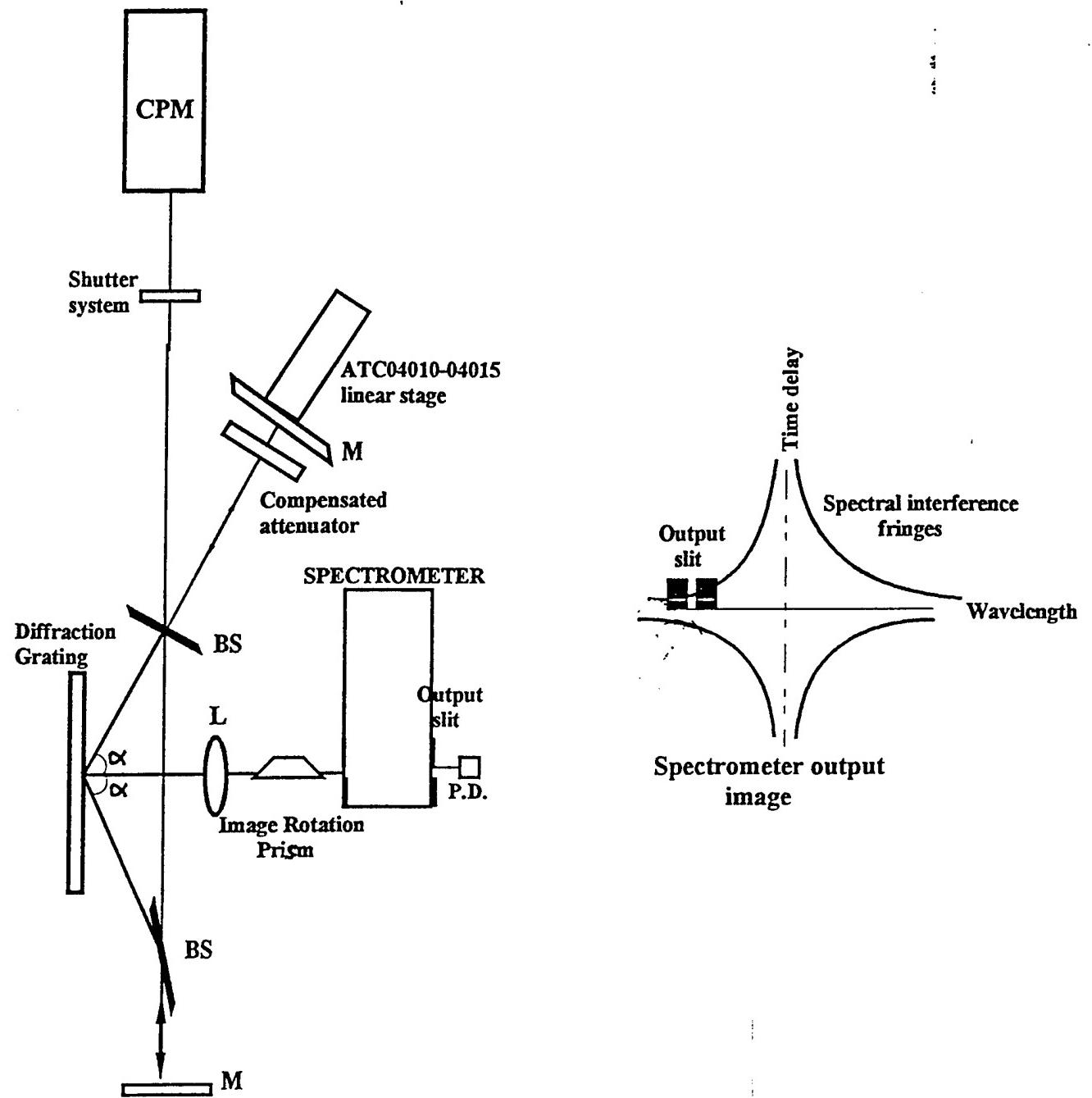
## **2. Instrument for spectral phase and pulse shaping measurements.**

Today the most commonly used for spectral phase measurement of a pulse is the nonlinear autocorrelation. While this technique generally require high intensity pulses, the spectral phase of femtosecond pulse can be measured using proposed frequency domain correlator. This technique involves cross correlating different spectral slices of the original pulse with itself. The relative delay of the spectral components with respect to each other provides information about any chirp which may be present. The spectral correlator was performed so that signal beam includes zero-dispersion stretcher with moving slit placed in the stretcher spectral plane to measure dependence of the output signal position on the slit position (Fig. 2 ).

The Ti:sapphire oscillator, interferometric correlator, CCD camera, zero-dispersion pulse stretcher were used to build spectral correlator. The derivative of the spectral phase ( $d\phi/d\omega$ ) of the Ti: sapphire oscillator femtosecond pulses were measured using this system. Measurements showed that  $d\phi/d\omega$  has small deviation (less than 15 fs) along Ti: sapphire pulses spectrum.

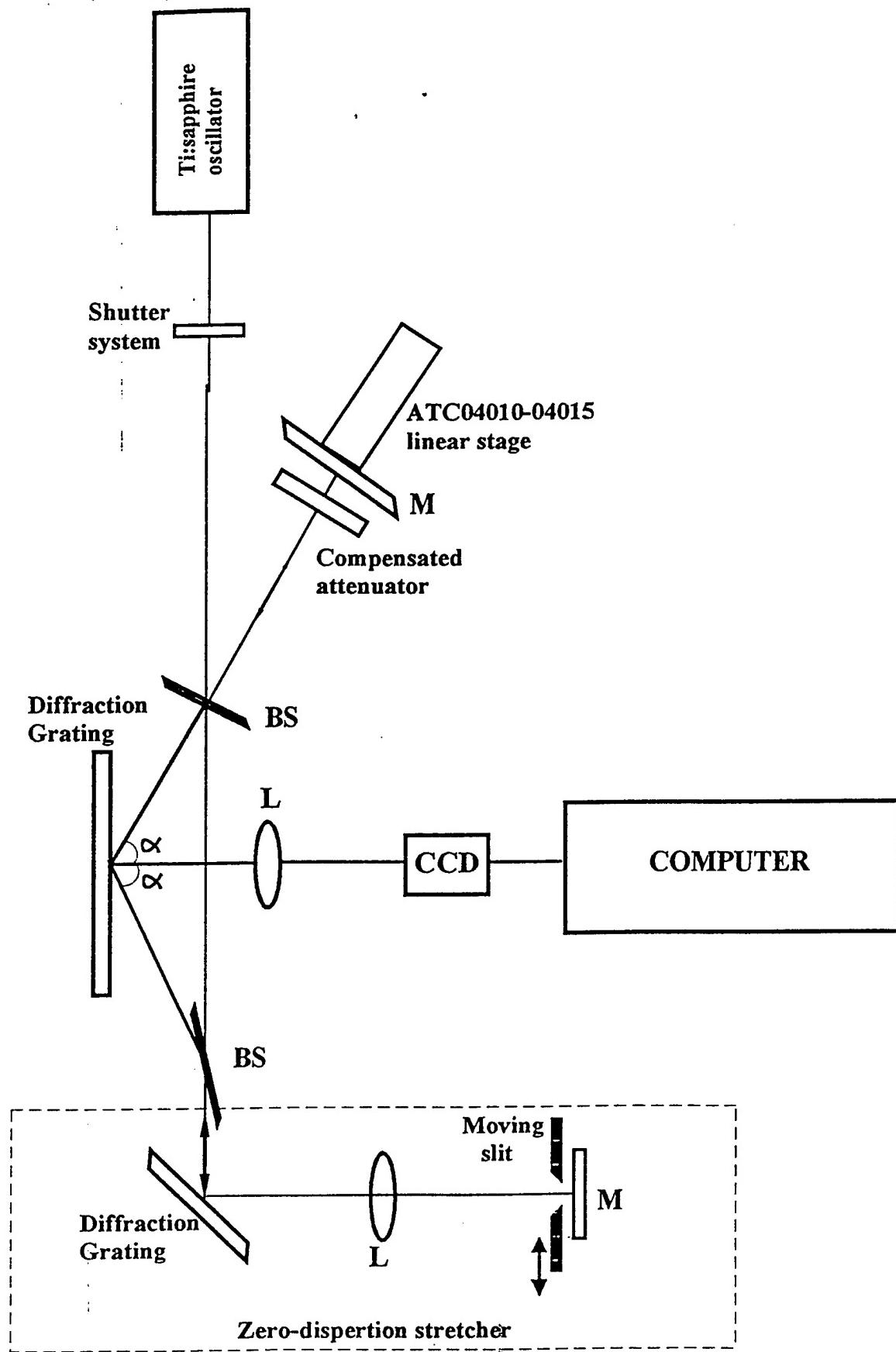
## **3. Heterodyne grating-generated temporal scan interferometric correlation system.**

Signal to noise ratio and acquisition speed of the interferometric correlation system can be increased using modulated grating-generated coherent temporal scan by parallel moving (shaking or rotating) grating and Doppler shift heterodyne detection by parallel diode linear array fast registration. When the light beam diffracts by the moving



**Figure 1. Spectral correlator to characterize the phase stability of pulse stream.**

P.D.:photodiode; M:mirror; BS:beamsplitter; L:lens



**Figure 2. Correlator for spectral phase measurements**

**BS:**beamsplitter; **M:**mirror

diffraction grating ( DG ) than the frequency of the diffracted light has Doppler shift. Consider DG moving in the direction of the grating dispersion ( x-axes ) with constant speed  $v$ . The projections of the speed vector  $\mathbf{V}$  on the direction of the reference ( signal ) beam are  $V_{r,s} = \pm v \sin\alpha$ , where  $\pm \alpha$  is the angle between the reference ( signal ) beams and the normal to the DG. The Doppler frequency shift between diffracted reference and signal beams is

$$\Delta f_D = 2 v f_0 \sin\alpha / c = 2 v \sin\alpha / \lambda_0 = 2v / p,$$

where  $p$  is the space between DG grooves.  $f_0$ ,  $\lambda_0$  are light frequency and wavelength.

For example, if  $v=30$  mm/s and  $p=0.001$ mm than  $\Delta f_D = 2 \times 30 / 0.001 = 60$ KHz. The output interference signal will be temporal modulated with frequency equal of  $\Delta f_D$ . This optical signal is directed to the multichannel linear array ( L.A.) detector or a single photodiode. The optical signal is detected by demodulating the detector output at the Doppler shift frequency.

The interferometric correlator will be used for optical communications, optical imaging and optical storage programs such as a receiver of a pulse code signal and retrieved from an optical memory system using hole-burning holography. The pulse code signal is directed on the grating at the diffraction angle  $\alpha$  and coherent reference pulse is directed on grating at the diffraction angle -  $\alpha$ . For time-display window of 20 ps and the pulse amplitude correlation time of 100 fs the pulse code has about  $2 \times 10^3$  bit. The information reading speed of  $2 \times 10^9$  bits/s and the SNR about 100 dB can be achieved. This system under development is shown schematically in Fig. 3. Two proposed systems will be investigated: with single diode and linear diode array.

Interferometric correlator, pulse shaper with SLM-256 spatial light modulator masks, moving diffraction grating by ATC04015 linear stage were acquired and will be used for an optical memory system to produce and read out a femtosecond pulse code signal and for medical imaging of tissue structures. The use of these interferometric correlators for different applications will result in vary publications in the future.

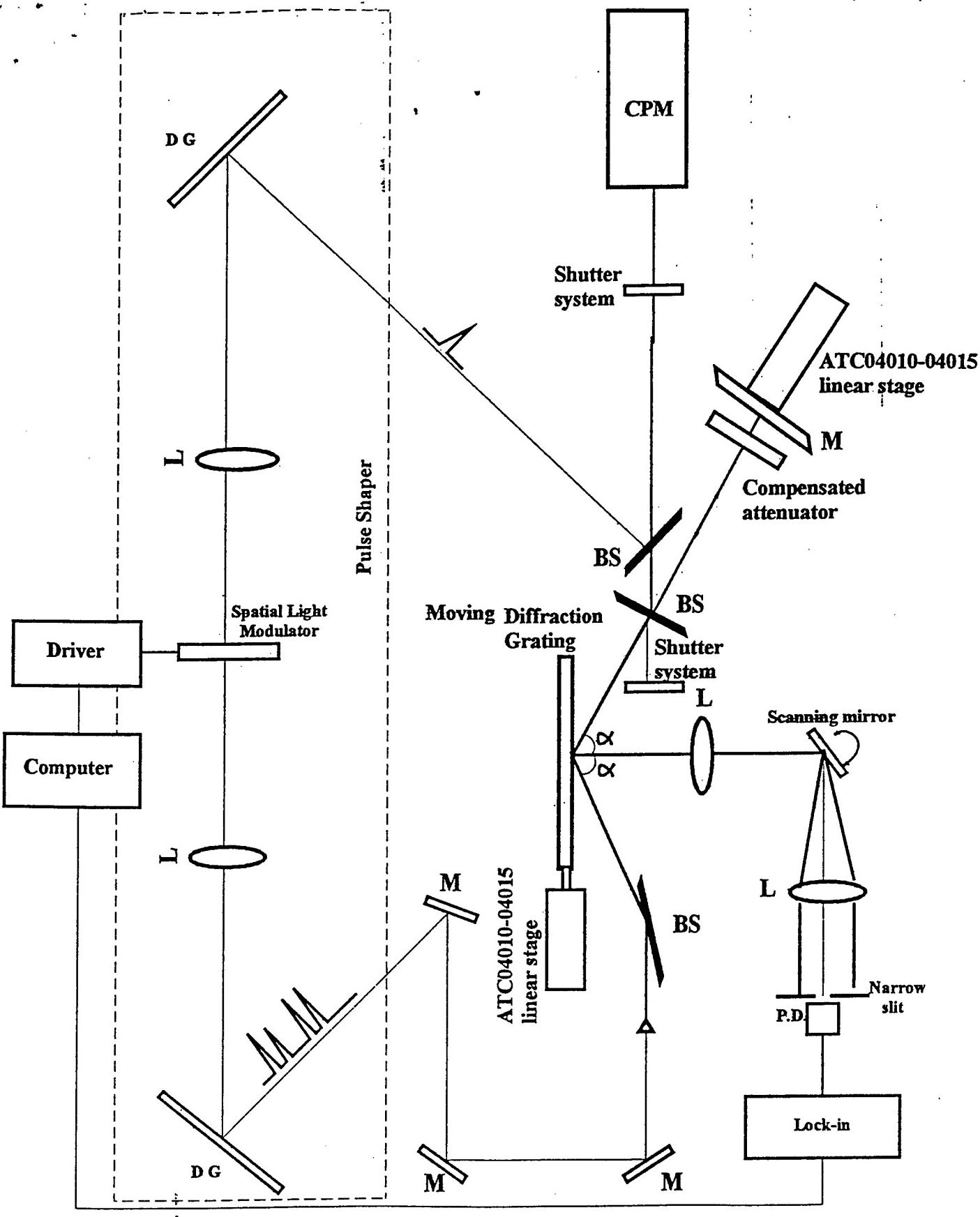


Figure 3. Heterodyne grating-generated temporal scan correlator.

P.D.:photodiode; M:mirror; BS:beamsplitter; L:lens; DG: diffraction grating